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5G New Radio in mmWave Spectrum Bands 70 GHz Coexistence (5G to Backhaul)

July 12, 2017

5G New Radio – 70 GHz Coexistence (5G to Backhaul)

Summary/Outline

- Minimal 5G to backhaul interference
  - Geometry of existing backhaul deployments limits opportunity for 5G UE interference
  - 5G UEs at street level, incumbent backhaul receivers are typically high and above the clutter
  - Case study of Lincoln Park neighborhood in Chicago showing impact of UE interference
- Passive Mitigation
  - 5G gNB (i.e. 5G base station) placement by design can minimize interference
  - 5G UE will have active arrays (e.g. 32 elements) having beam directions that are reciprocal to 5G gNB beams
  - Examples of gNB placement to limit UE interference
- Active Mitigation
  - Few problematic links can employ 5G Rx probe co-located with the backhaul link receiver
  - Detected interference can disable a sub-set of 5G gNB beams preventing re-occurrence of interference incident
- Backhaul Evolution @ 70 GHz
  - Existing backhaul nodes will be protected in the current form having minimal interference
  - Future backhaul receivers should be 5G NR aware enabling efficient and effective coexistence
  - Recommend that interim backhaul deployments require contemporary wireless implementation with resilience to sparse impulsive interference.

5G NR and Existing Backhaul can coexist and impact of UE interference is minimal

5G NR – 70 GHz Coexistence

Minimal 5G to backhaul interference

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5G New Radio – 70 GHz Coexistence (5G to Backhaul)

Minimal 5G to backhaul interference

- Four databases, each covering an area of radius 300km

Region	West coast					Midwest			East coast	
Database	Los Angeles		San Francisco			Chicago			New York	
	All	Fin. Dist.	All	Bay Area	Union Square	All	Lincoln Park	Loop	All	Lower Manhattan
No. of links	1013	133	1892	73	814	1743	40	67	5303	245
No. of pairs	911	127	1801	68	797	512	40	51	1685	184

- A link is defined as a two-way connection between two fixed stations over a specific channel
- A pair is defined as a link with unique (Longitude, Latitude) coordinates of the fixed stations.

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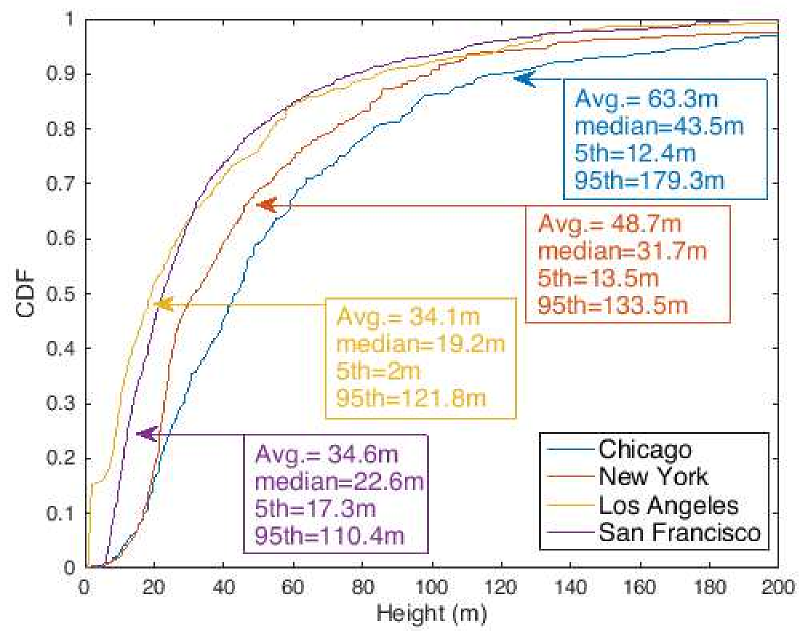
Minimal 5G to backhaul interference

- Median height of fixed station receivers is 20 meters
  - Appears correlated with the average building heights
  - Heights in Chicago and New York greater than San Francisco and LA
- 95% of fixed station receivers greater than 12 meters in most metropolitan areas
  - New York, Chicago & San Francisco have a common 5th percentile
  - LA show 2m above terrain for nodes (this requires further investigation)
- 5G cell sites will typically be 4 to 6 meters for street level deployments below the fixed station receivers



95% of fixed station receivers greater than 12 meters in most metropolitan areas while 5G cell sites will be only 4 to 6 meters

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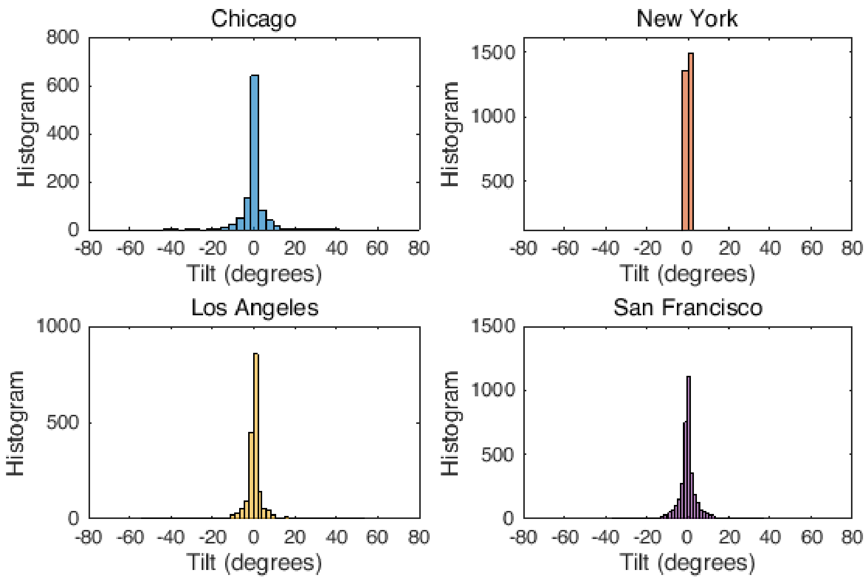
Minimal 5G to backhaul interference

- The vast majority of fixed station nodes have a receiver tilt angle pointing horizontally
  - New York, Chicago and LA have over 99% of the fixed station receivers with +/- 10 degree tilt angle
  - San Francisco’s hilly terrain is an exception but likely will have tilt angles pointed above the building tops and therefore above the 5G cell coverage



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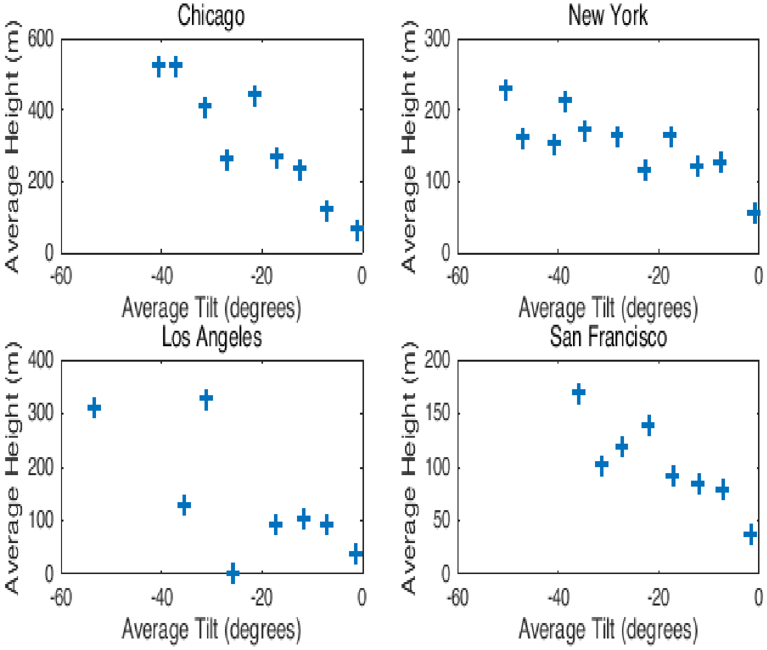
Minimal 5G to backhaul interference

- Few fixed station nodes have tilt angles pointing to the street level
- Larger negative tilt angles are correlated with higher building height
- *5G interfering signals will typically see a larger path loss given the height of victim receivers*



Majority of fixed station nodes have a receiver tilt angle pointing horizontally thus minimizing 5G UE interference to backhaul nodes

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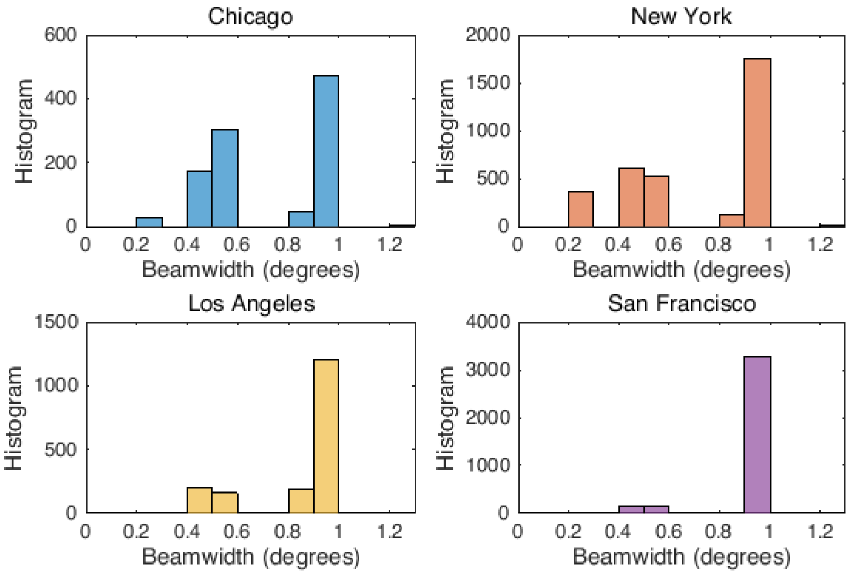
Minimal 5G to backhaul interference

- Beamwidths for fixed station receivers are always narrow
- Per statute, the beamwidths are limited to 1.2 degrees
- Most 5G signals will be highly attenuated falling outside the victim receiver's beam



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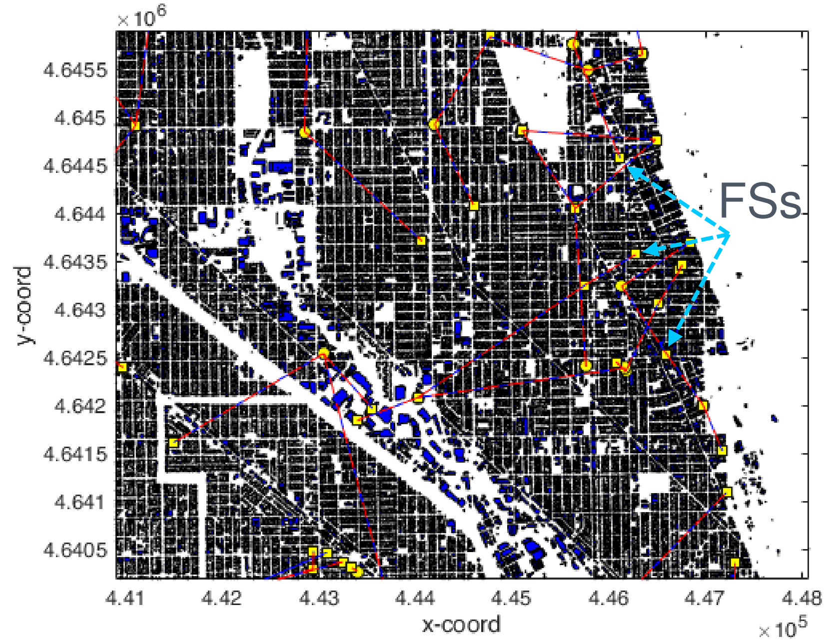
Minimal 5G to backhaul interference – Summary

- 95% of fixed station receivers are at heights greater than 12 meters in most metropolitan areas while 5G cell sites will be only 4 to 6 meters above the ground for street level deployments and consequently will be well below the fixed station receivers
- The vast majority of fixed station nodes have a receiver tilt angle pointing horizontally directed above the 5G deployments
- Most 5G signals will be highly attenuated falling outside the victim receiver's beam as fixed station receiver beamwidths are exceptionally narrow per statute having beamwidths less than 1.2 degree

5G New Radio – 70 GHz Coexistence (5G to Backhaul)

Lincoln Park Sim Results - Geometry

- A building database of Lincoln park (LP) is used to find blockage: 66 fixed stations
- Blockage depends on
  - Location of fixed station node
  - Location of 5G UE
  - Building location, geometry, and height
- Antenna attenuation depends on
  - Tilt of the receiver fixed station (FS)
  - Relative location of UE-FS link to FS-FS link



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Lincoln Park Sim Results - Parameters

- No. of users is based on Lincoln Park:
  - The system is dynamic Time Division Duplex (TDD), but the analysis focuses on uplink transmissions in uplink slots
  - A 25% instantaneous load is assumed in the available uplink slots
  - Each site covers a region of 200x200m^2 with 4 sectors per site for a total of 917 sites in the simulation area (6416x5718m^2)

** The 33dBm EIRP is based on
  - UE with 32 antennas (4x4x2)
  - An antenna gain of 5dBi per element
  - A transmit power of 1dBm per element

Parameter	Values
Path loss	
Carrier frequency (GHz)	71-76 GHz, 81-86 GHz
Channel model	NR-UMi with actual blockage calculations instead of probabilistic
5G UE	
No. of users*	920 uplink UEs schedule per subframe
EIRP (dBm)**	33.3 and 43
Locations	Randomly deployed outdoors
Antenna height (m)	1.5
Fixed stations (FSs)	
Locations/height	From database
Antenna gain	
Noise figure	
Temperature (K)	290
Bandwidth (GHz)	1

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Lincoln Park Sim Results - Calculations

Omni-directional Path loss

- $\mathrm{omniPL_{dB}} = \mathrm{PL_{out}}(\mathrm{blockFlag}) + \mathcal{X}(\mathrm{blockFlag})$

where

- $\mathrm{blockFlag} = 1$ if the link is NLOS, i.e., blocked by a building
- $\mathrm{PL_{out}}(\mathrm{blockFlag}) = (\mathrm{blockFlag} \times \mathrm{PL_{NLOS}}) + (\sim\mathrm{blockFlag} \times (\mathrm{PL_{LOS}}+\mathrm{PL_{Veg.}}))$
- $\mathrm{PL_{Veg.}}$ is the vegetation loss
- $\mathcal{X}$ is log-normal shadowing with standard deviation that depends on LOS/NLOS.

Interference

- $I_{\mathrm{dBm}} = \mathrm{EIRP_{UE}} + \mathrm{G_{FS}} - \mathrm{omniPL_{dB}}$

where

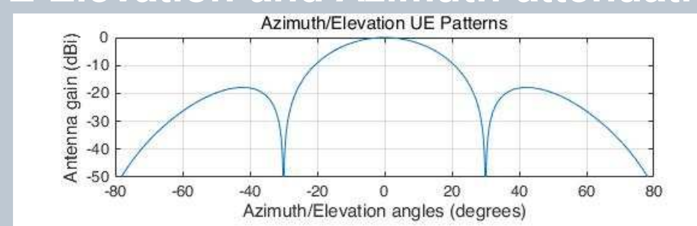
- $\mathrm{EIRP_{UE}}$: UE maximum EIRP (dBm)
- $\mathrm{G_{FS}} = \mathrm{G_{max}} + \max(\mathrm{A_e} + \mathrm{A_a}, \mathrm{FTBR_{dB}})$ given in dBi
- $\mathrm{G_{max}}$: maximum antenna gain (dBi)- given from the database
- $\mathrm{A_a}$: Azimuth attenuation (dB) [source: FCC 47CFR101.115]
- $\mathrm{A_e}$: Elevation attenuation (dB) [source: FCC 47CFR101.115]
- $\mathrm{FTBR_{dB}}$ Front-to-back-ratio loss (assumed to be -50dB)

FS Elevation and Azimuth attenuation

- $\mathrm{A_{\{.\}}} = f(\mathrm{G_{max}}, \theta)$

$$== \begin{cases} \mathrm{G_{max}}, & \theta = 0 \\ \mathrm{G_{max}} - 2.5\theta, & 0 < \theta \leq 1.2 \\ \vdots & \end{cases}$$

UE Elevation and Azimuth attenuation



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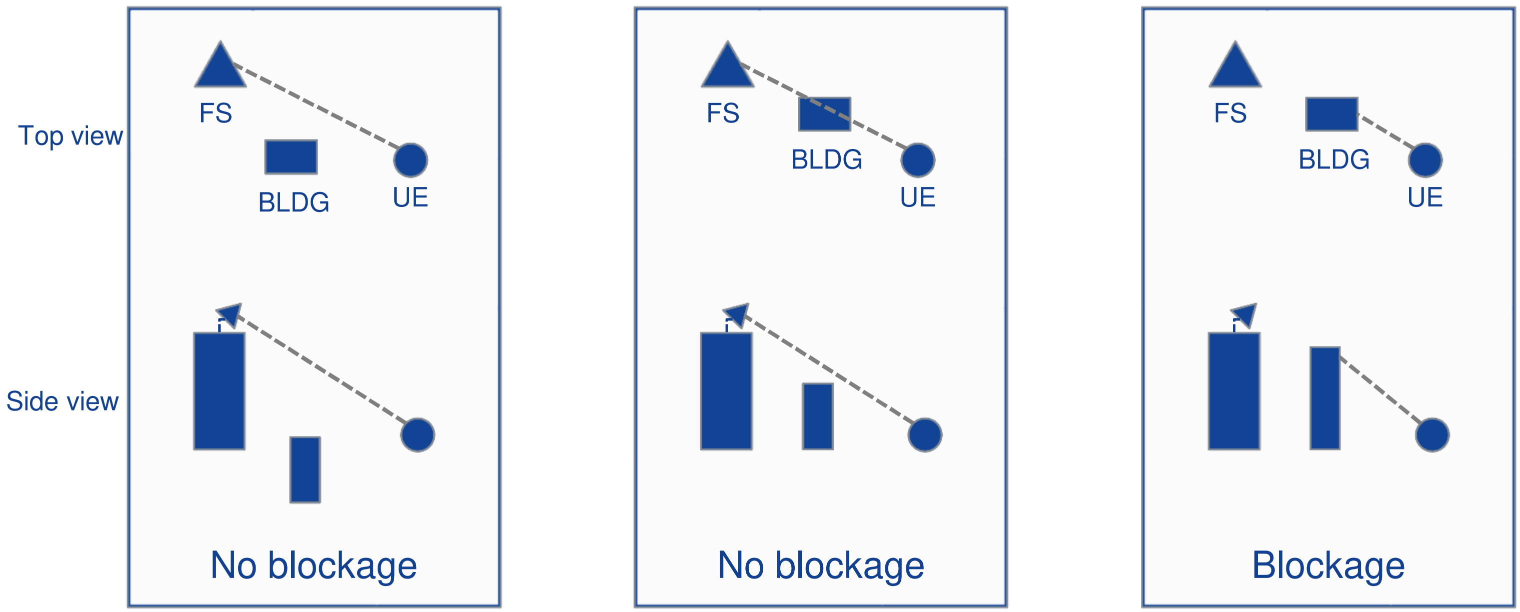
Lincoln Park Sim Results - Finding blockage



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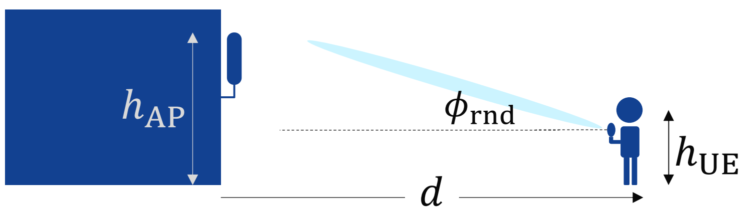
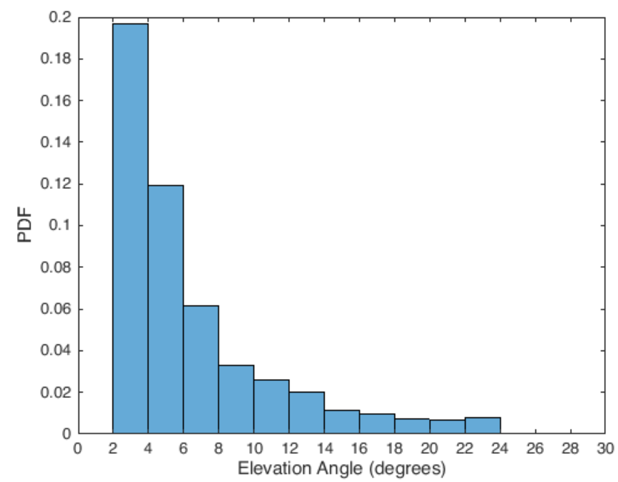
Lincoln Park Sim Results – Modeling UE direction

- Azimuth is uniformly distributed $\theta_{\mathrm{rnd}} \sim \mathcal{U}(0{,}360)$
- Elevation is randomized as $\phi_{\mathrm{rnd}} = \mathrm{atan}\left(\frac{h_{\mathrm{AP}} - h_{\mathrm{UE}}}{d}\right)$
  - $h_{\mathrm{AP}} = 6$m; $h_{\mathrm{UE}} = 1.5$m; $d \sim \mathcal{U}(10{,}100)$m





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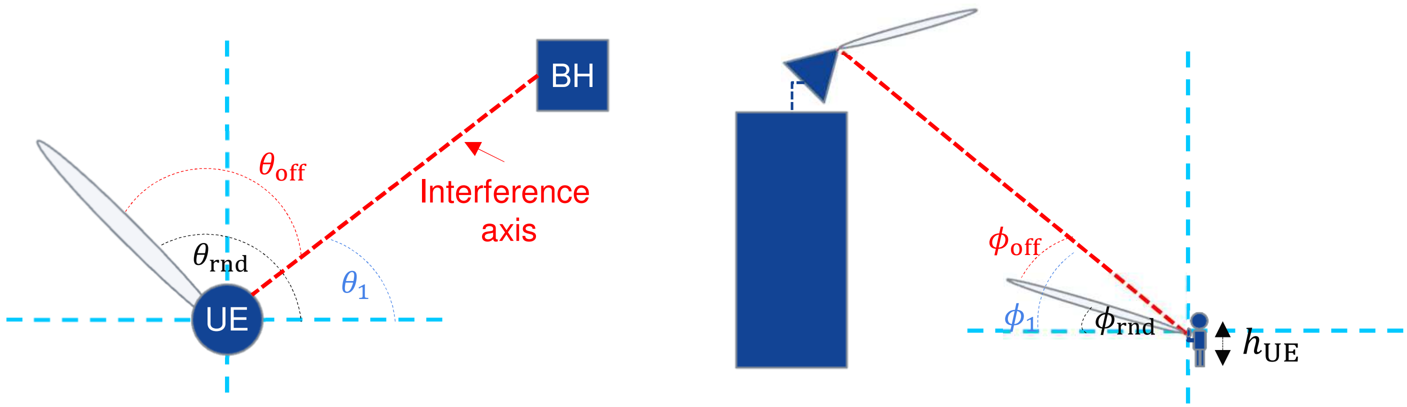
Lincoln Park Sim Results – Modeling UE direction

- UE antenna attenuation: $\min\{A_{\mathrm{a,off}}(\theta_{\mathrm{off}}) + A_{\mathrm{e,off}}(\phi_{\mathrm{off}}), A_m\}$
  - $A_{\mathrm{a/e,off}}$: Attenuation in azimuth/elevation due to off-axis angle (w.r.t. to the interference axis)
  - $\theta_{\mathrm{off}} = \theta_{\mathrm{rnd}} - \theta_1$ and $\phi_{\mathrm{off}} = \phi_1 - \phi_{\mathrm{rnd}}$
  - $A_m = 30$dB (front-to-back ratio loss)



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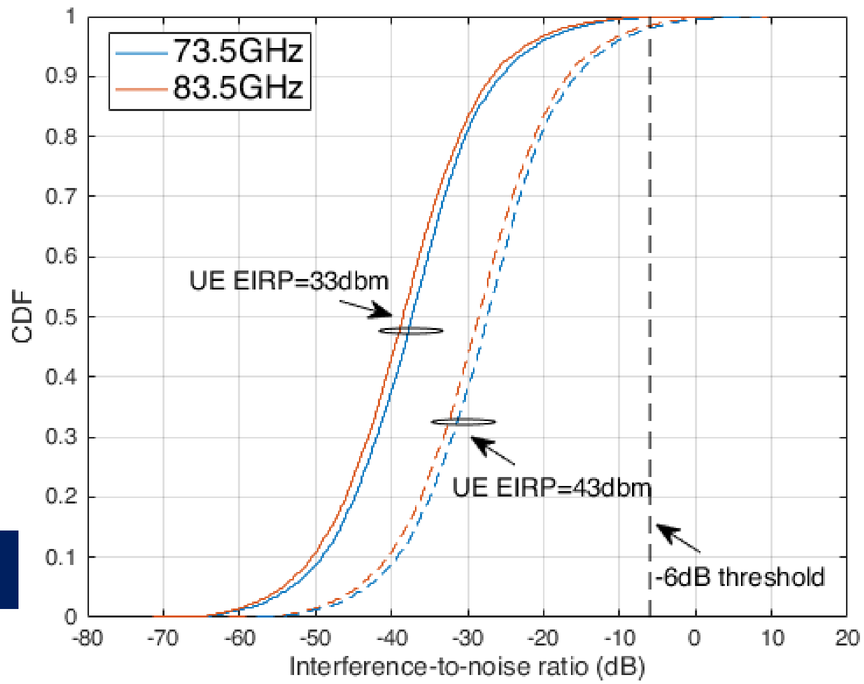
Lincoln Park Sim Results – CDF of INR

- Distribution of INR added to FSs is shown for different center frequencies and UE EIRP
- Interference is well below the noise floor of FSs
  - 95th percentile = -8.9dB for 73.5GHz and 43dBm



Lincoln Park: Interference well below the noise floor

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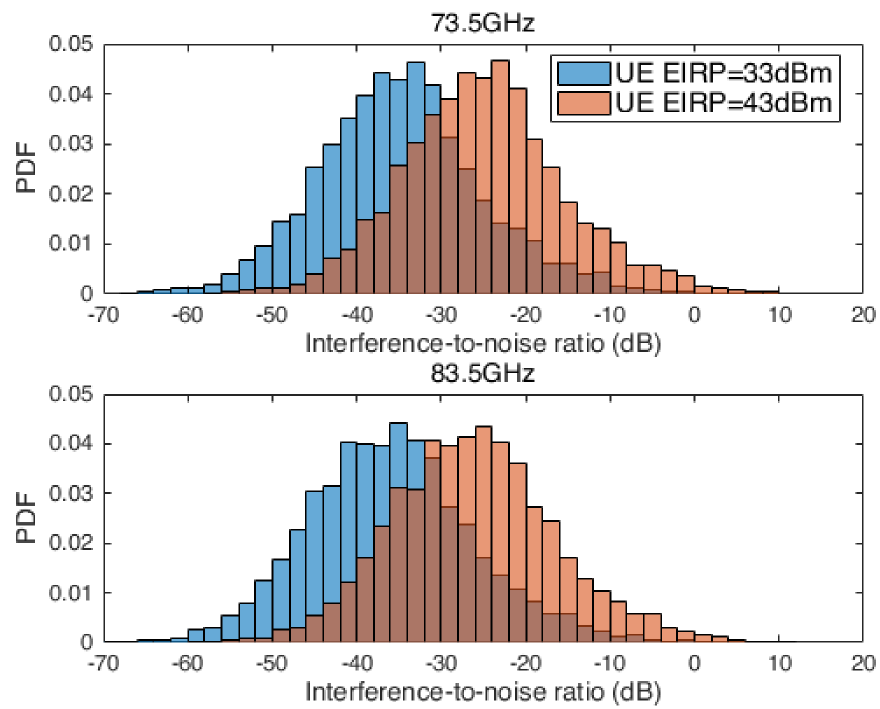
Lincoln Park Sim Results – PDF of INR

- Probability density function of INR added to FSs is shown
- INR is very low and the probability of INR< -6 dB is 97% for EIRP 43dBm and 99.7% for EIRP 33dBm
  - Buildings provide significant blockage of UE transmissions, protecting FSs
  - It is unlikely that a UE aligns perfectly (<1degree) with the FS
  - FSs pointing to ground are already at high altitudes, increasing the distance to UE → significant attenuation @70/80GHz



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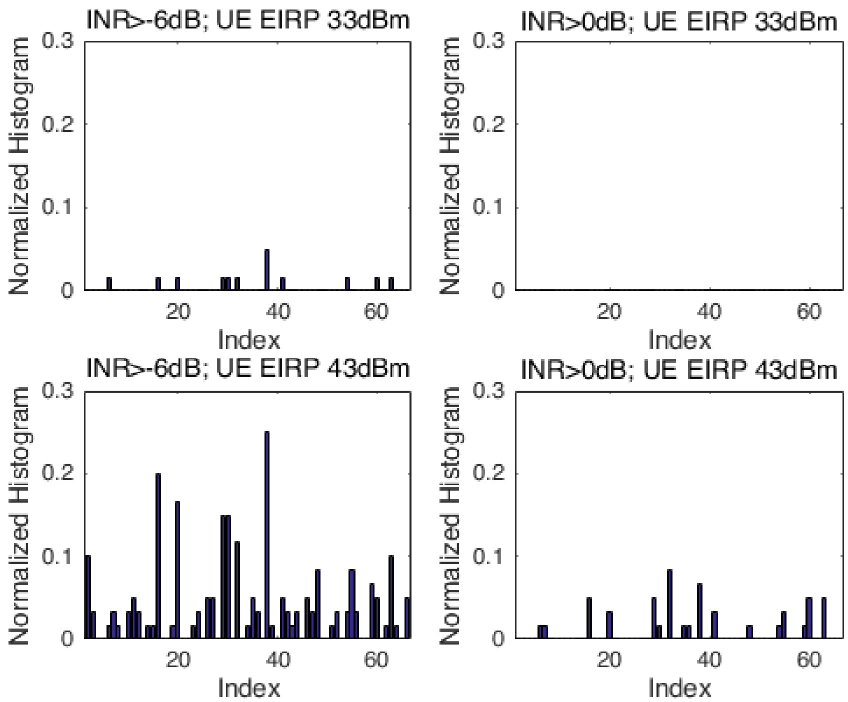
Lincoln Park Sim Results – Occurrence of INR > t per victim

- Probability of interference exceeding a threshold at particular victim receiver is shown for both 33 dBm and 43 dBm UE transmissions and 73.5GHz
- The charts clearly show a trend where some nodes see victim receivers are more susceptible to interference than others, specifically 16 and 38



Higher UE transmit power increases the need for specific mitigation techniques

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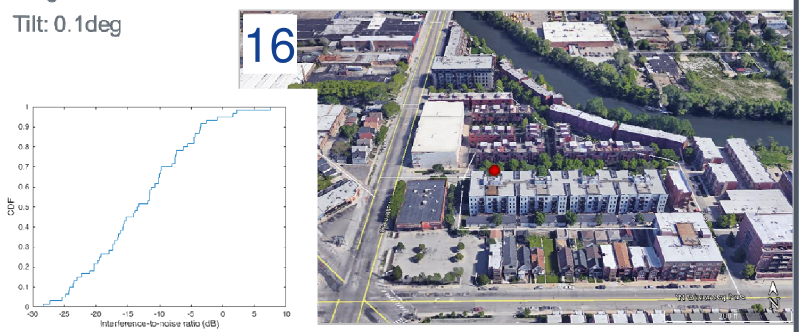
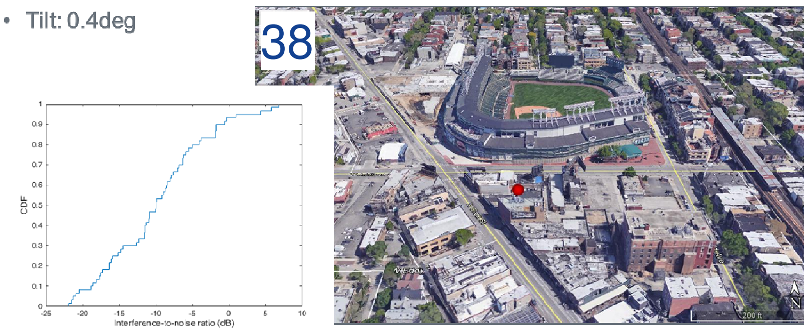
Lincoln Park Sim Results – Most susceptible fixed backhaul nodes

- Height: 21.03m
- Tilt: 0.1deg



- Height: 21.43m
- Tilt: 0.4deg



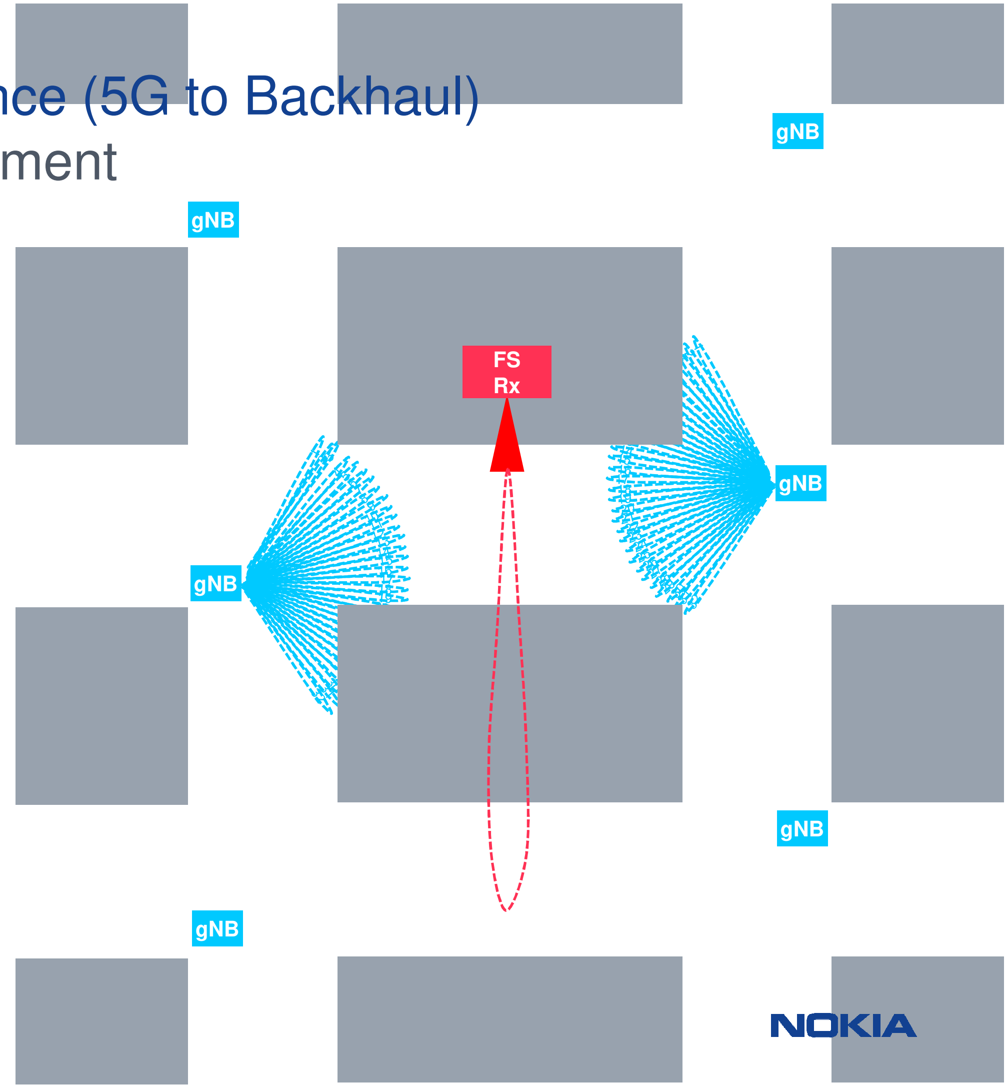
- All nodes have relatively low height yet clear sight lines as result of open space
- Mitigation techniques will need to avoid these sight lines with perpendicular coverage of streets
- Similarly exclusion angles can be created to avoid beams pointed at these receivers

5G NR – 70 GHz Coexistence

Passive Mitigation

5G New Radio – 70 GHz Coexistence (5G to Backhaul)
Passive Mitigation – 5G gNB Placement

- *5G gNB placement by design can minimize interference*
- Urban canyons where FSs are deployed offer inherent protection from building and structures
- 5G gNB placement can design 5G beam coverage perpendicular to victim receivers to eliminate 5G interference in most cases
- 5G gNB placement can be adjusted such that buildings and other blockers can be employed to effectively shadow the victim receiver from 5G gNB interference



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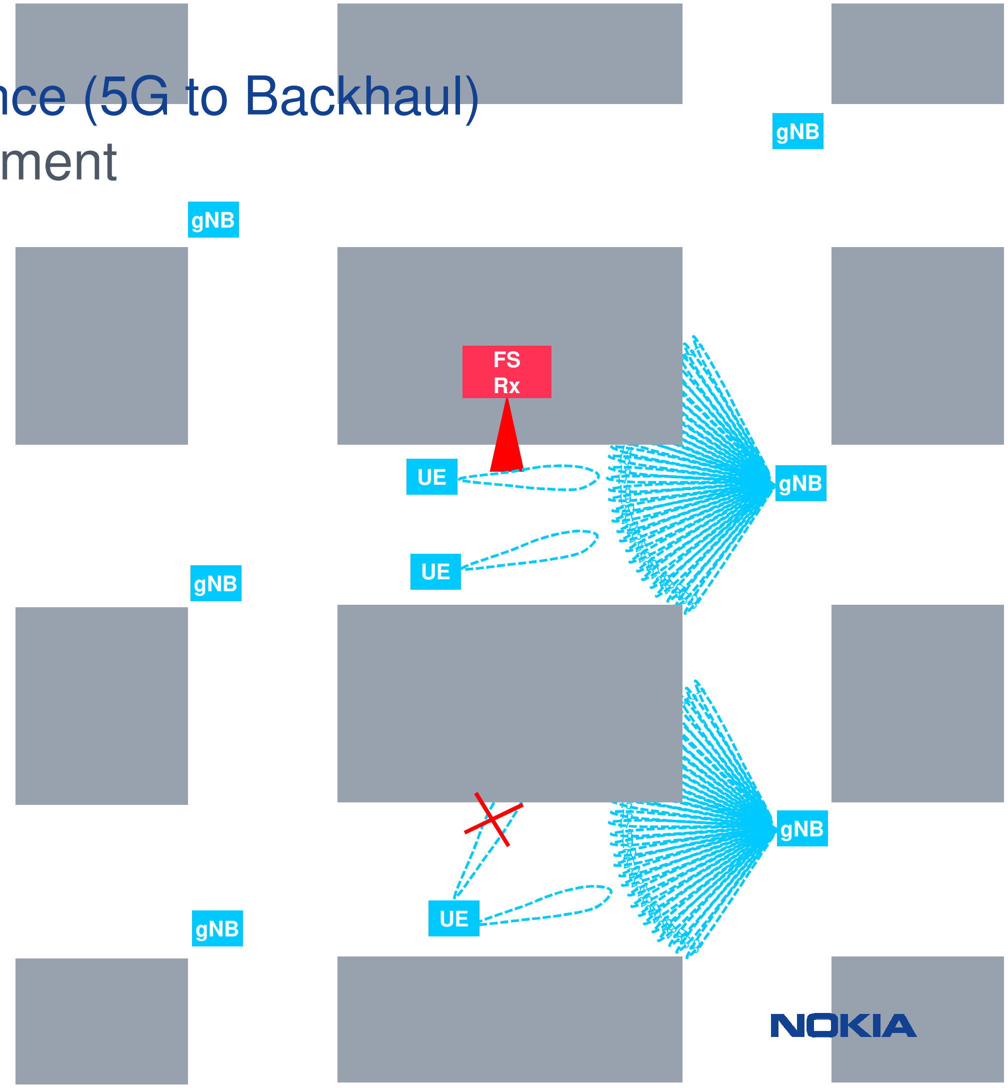
Passive Mitigation – 5G gNB Placement

- *5G UE beam directions are reciprocal to those of 5G gNBs*
- 5G UE transmission directions will also be governed by 5G gNB placement
- 5G UE beam transmission will be perpendicular to victim receivers if 5G gNB coverage is designed to be perpendicular
- Correspondingly, 5G gNB placement can be adjusted such that buildings and other blockers can be employed to also shadow the victim receiver from 5G UE interference



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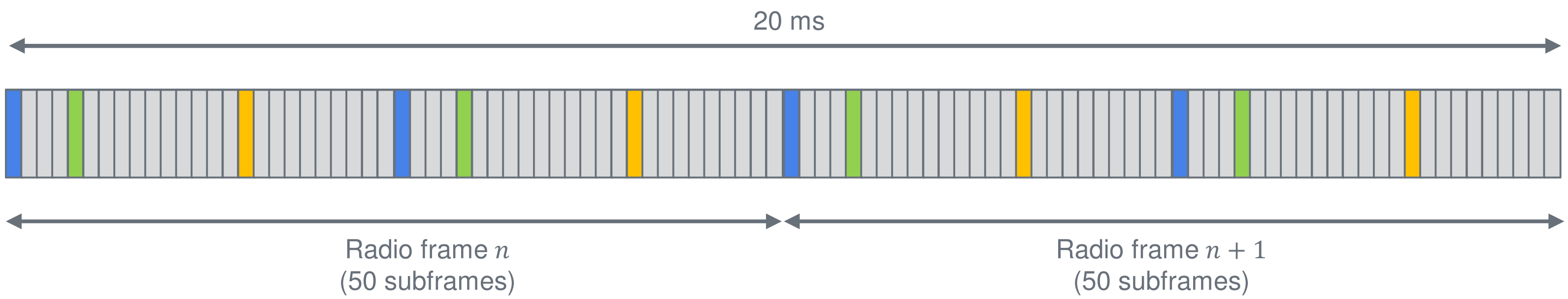
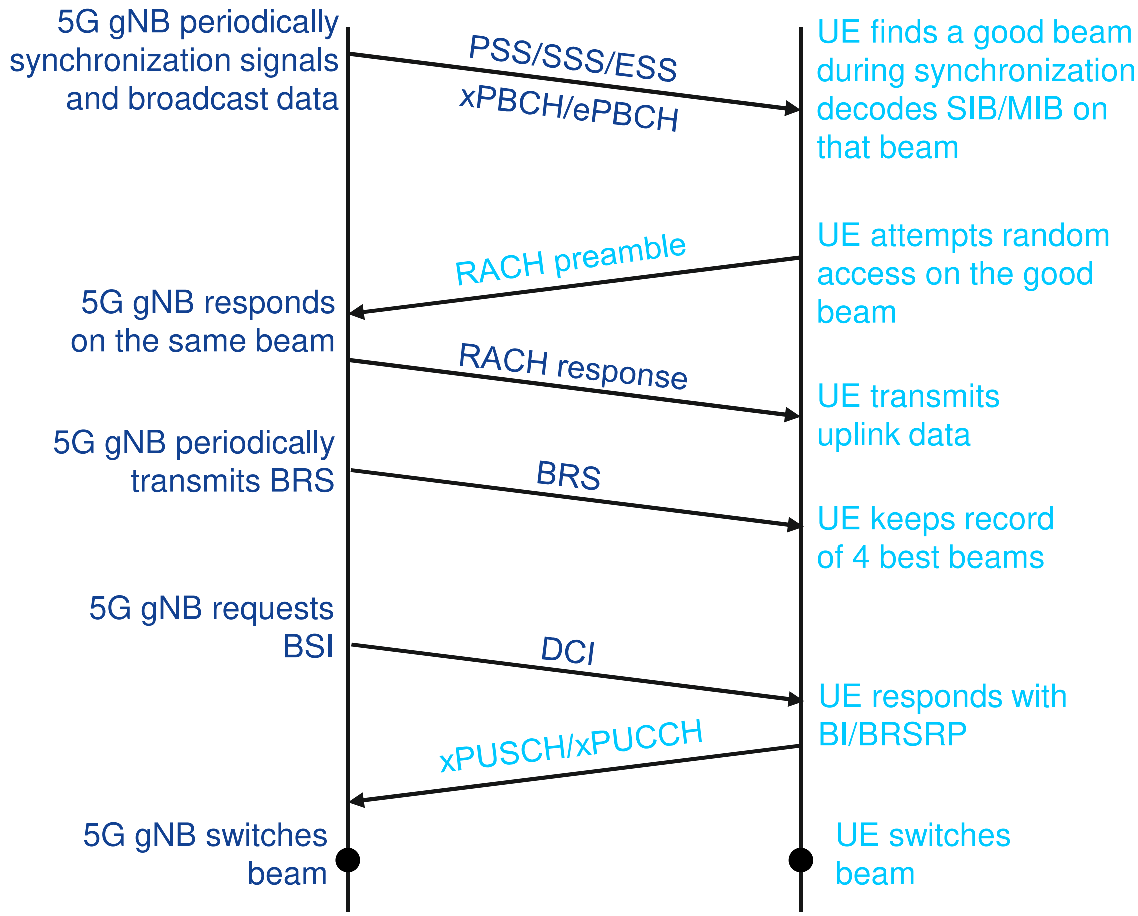
Example TDD frame structure for 5G



BRS/Synch/xPBCH	→ Used for beam training, timing and frequency synchronization, broadcasting
ePBCH	→ Contains system information block containing essential information for initial access
xPRACH	→ Random access, scheduling request, beam change request
xPUCCH/xPUSCH/ xPDCCH/XPDSCH	→ Uplink/ Downlink control and data channels

Example 5G beamforming procedure



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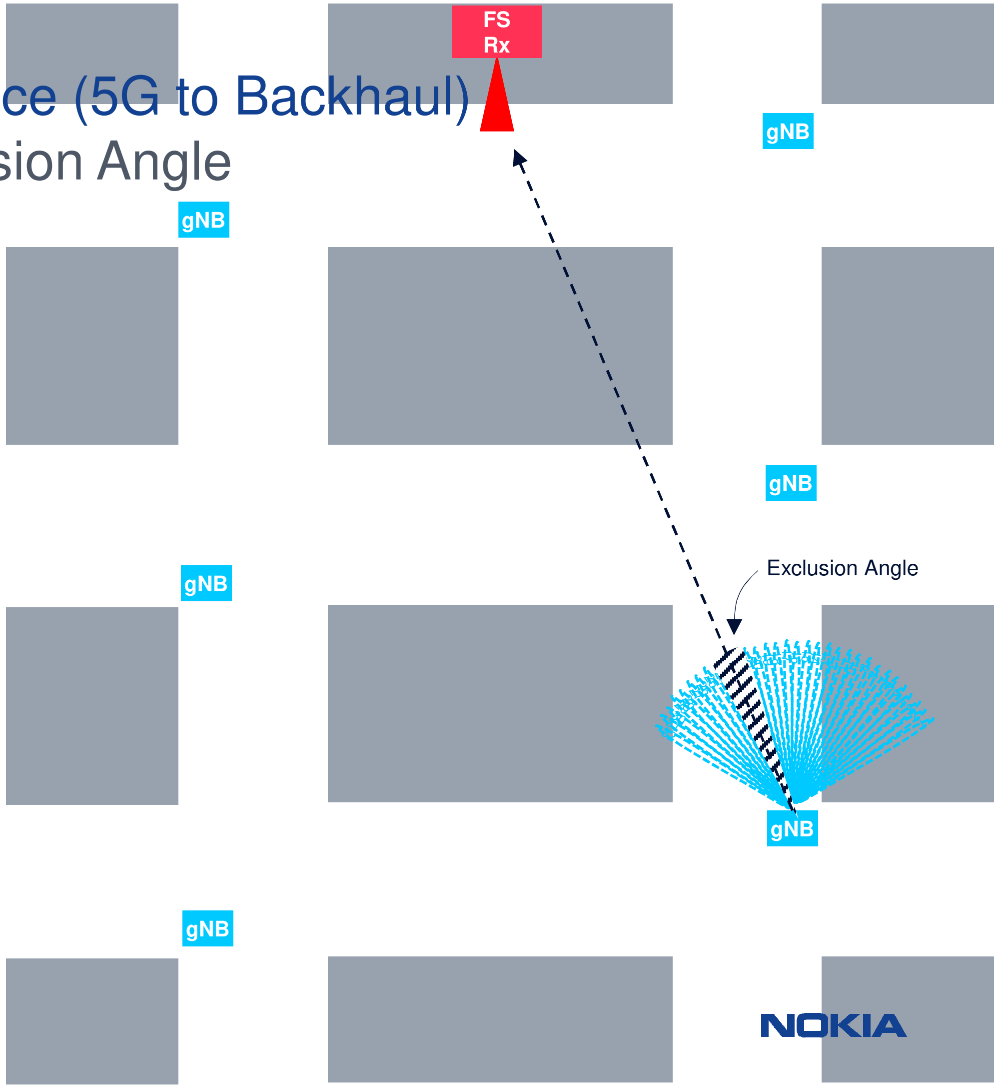
Passive Mitigation – 5G gNB Exclusion Angle

- *5G gNB beam management can minimize interference by avoiding offending beams*
- 5G gNB can employ exclusion angles to omit beams directed at a victim receiver
- Exclusion angles can be employed in both azimuth and elevation
- The width of exclusion angles will depend on the array size and therefore beamwidth of the 5G gNB
- Holes in 5G gNB coverage from exclusion zones may be addressed by neighboring cell



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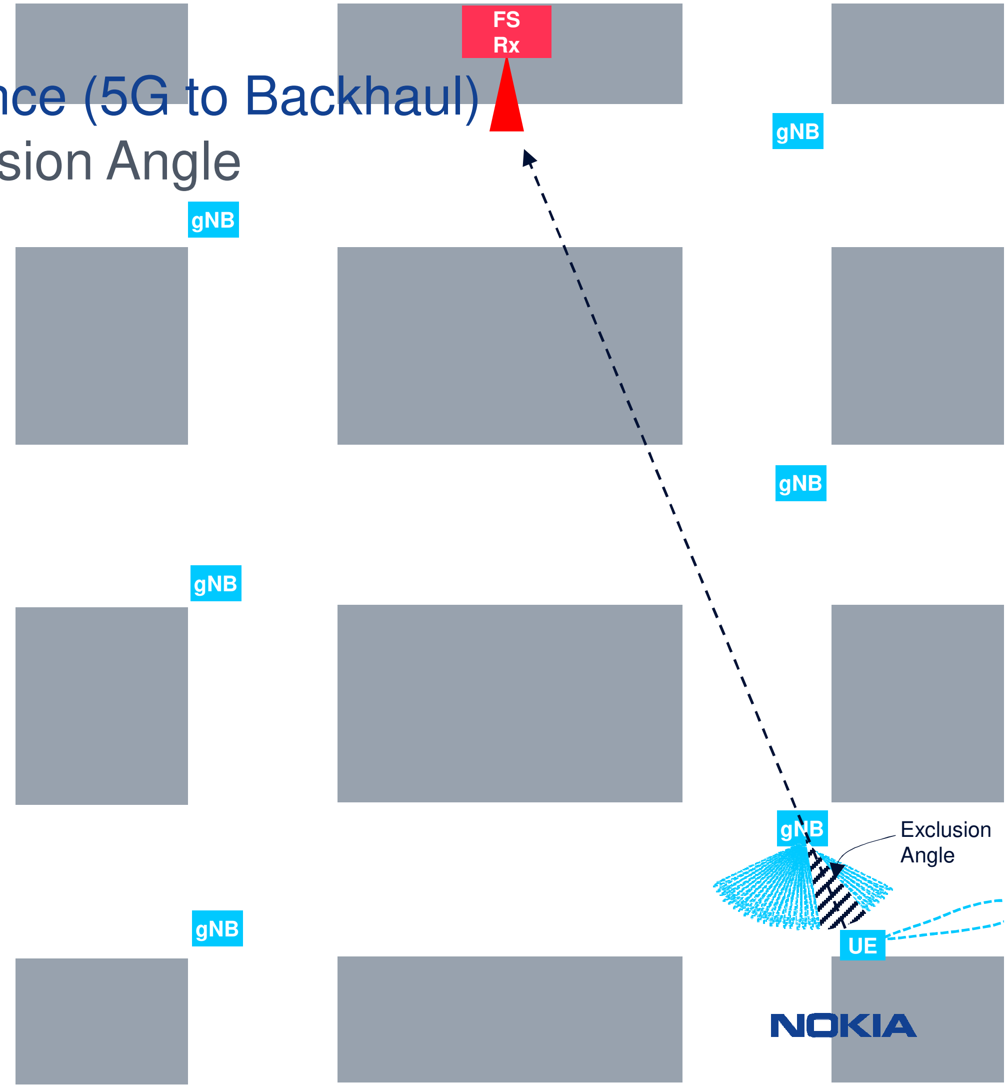
Passive Mitigation – 5G gNB Exclusion Angle

- *5G gNB beam management can minimize UE interference based on the principle of reciprocity*
- 5G gNB can employ exclusion angles to omit beams that correspond to 5G UE beams pointed at the victim receiver
- 5G UEs in exclusion zones would attach to neighboring 5G gNBs directing their beam away from the victim receiver
- It is acknowledged that 5G UEs may still attach to reflections of 5G gNB beams causing the UE to direct their beams in offending directions. This will be rare and 5G deployments must consider this for particularly susceptible victims



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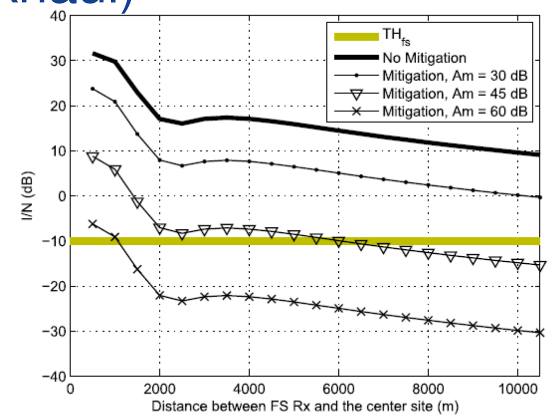
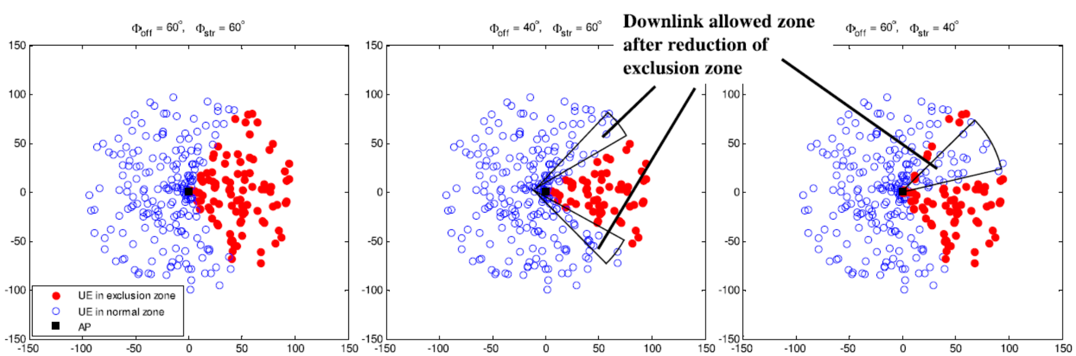
Previous studies on passive gNB mitigation

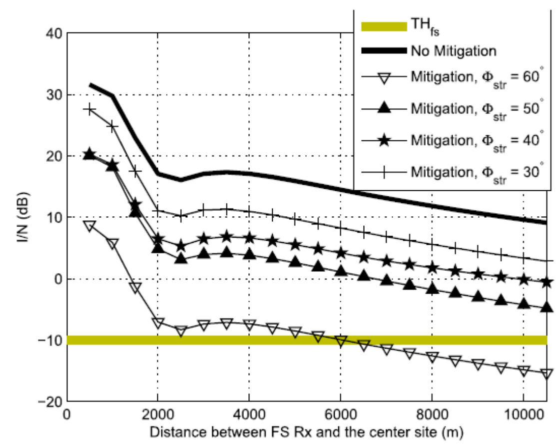
- In Nov 2016, Nokia shared results on gNB to fixed station interference showing exclusion angles are effective
- A statistical model was used to calculate LOS probability
- Results recently published here:

  Seungmo Kim, Eugene Visotsky, Prakash Moorut, Kamil Bechta, Amitava Ghosh and Carl Dietrich, “Coexistence of 5G With the Incumbents in the 28 and 70 GHz Bands,” IEEE JSAC, *vol.35*, *issue 6*, June 2017.





(a) $\Phi_{off} = 60°, \Phi_{str} = 60°$ (b) $\Phi_{off} = 40°, \Phi_{str} = 60°$ (c) $\Phi_{off} = 60°, \Phi_{str} = 40°$



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Passive Mitigation – Summary

- 5G gNB placement by design can minimize interference by controlling beam point direction of gNBs and employing blockers to shield victim receivers
- 5G gNB placement may also minimize interference from 5G UEs based on the principle of reciprocity. UEs beam direction will be directed at gNBs and therefore may be managed by gNB placement
- 5G gNB beam management can minimize interference by avoiding offending beams through the use of exclusion zones protecting victim receivers. Coverage omitted by an exclusion zone can be addressed by a neighboring cell
- 5G gNB beam management can also minimize UE interference based on the principle of reciprocity. gNB exclusion zones can be used to protect victim receivers from UE offending beams.

Passive Mitigation can be achieved by 5G eNB placement and Beam Management

5G NR – 70 GHz Coexistence

Active Mitigation

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Active Mitigation – Introduction

- Active mitigation involves placing a 5G probe at the victim receiver that is 5G protocol compliant
  - The 5G probe will be able to detect an offending beam from either a UE or gNB
  - The 5G probe will provide information on offending beams in real time such that interference can be remedied promptly
  - The 5G probe will provide sufficient information such that the gNB beam management system can identify the offending beams regardless of whether the beams were transmitted by a gNB or UE
- The 5G gNB beam management system can modify exclusion zones to remedy all future interference events for a given geometry (including reflections)
  - A specific gNB beam transmission in BRS subframe may be identified by the beam index when received by the probe. A gNB may identify the offending beam based on the beam index identification
  - A specific UE beam transmission in xPRACH subframe may be identified by the cell specific sequence and gNB listening beam index. A gNB may modify the exclusion zone based on the listening beam
- Offending beams can be detected quickly on the BRS subframe or xPRACH subframe to allocating a data channel (e.g. PDSCH and PUSCH)

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Active Mitigation – Comments

- Active mitigation need only be employed as a last resort for particular susceptible victim receivers who are not isolated by their inherent geometry or passive mitigation techniques
- Interference events prior to active mitigation would be of minimal duration as they can be detected on the a single symbol within a BRS subframe having a very short duty cycle prior to quieting (0.07% duty cycle)
  - The example is based on trial systems in 28 GHz having a beam reference symbol period of only 14 µs. Solutions at 70 GHz having a wider bandwidth can be designed even short on the order of 2 µs.
- Once detected future interference can be precluded as the gNB beam management system would learn of interference in the environment and construct the appropriate exclusion angles
  - An active management system could be employed in off hours in coordinated manner with incumbents prior to active service.

5G NR – 70 GHz Coexistence

Backhaul Evolution @ 70 GHz

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Backhaul Evolution @ 70 GHz

- Existing backhaul nodes will be protected in the current form having minimal interference
  - Either by the inherent geometry, passive mitigation or active mitigation
  - Current set of incumbent backhauls is relatively small and can easily be addressed by future inband 5G deployments
- Future backhaul receivers should be 5G NR aware enabling efficient and effective coexistence
  - Future backhaul deployments can be 5G NR aware having 5G probe built-in to actively mitigate interference in real-time more efficiently sharing the spectrum
  - 3GPP 5G NR has a planned study item called Integrated Access Backhaul (IAB) where 5G deployments will be self-backhauling. If successful, future fixed station can employ a common protocol with 5G access systems.
- Recommend that interim backhaul deployments require contemporary wireless implementation with resilience to sparse impulsive interference.
  - Impulsive interference as exhibited by a beam scanning transmission (BRS subframe) or random access attempt (xPRACH) will be of very short duration, as low 2 µs, and have a low duty cycle of 0.07%, can easily be compensated by known technology long employed by the 3GPP for mobile radio
  - Backhaul deployments in lightly licensed spectrum such as the 70 GHz band should be required to be resilient to sparse impulsive interference. Techniques such as adaptive hybrid ARQ employing both forward error correction and retransmission can easily mitigate sparse interference with negligible throughput degradation

5G NR – 70 GHz Coexistence

Summary

5G New Radio – 70 GHz Coexistence (5G to Backhaul)

Summary

- **Geometry of existing backhaul deployments limit opportunity for 5G UE interference**
  - 95% of fixed station receivers greater than 12 meters in most metropolitan areas while 5G cell sites will be only 4 to 6 meters for street level deployments and be well below the fixed station receivers
  - Most 5G signals will be highly attenuated falling outside the victim receiver's beam as fixed station receiver beamwidths are exceptionally narrow per statute
  - *Initial simulations in Lincoln Park have shown that INR < -8.9 for 95% of the observations for a maximum powered 5G UE*
- **Passive mitigation can further minimize interference**
  - 5G gNB placement by design can minimize interference by controlling beam pointing direction of gNBs and UEs and employing blockers to shield victim receivers.
  - 5G gNB beam management can minimize interference by avoiding offending beams through the use of exclusion zones protecting victim receivers. Coverage omitted by an exclusion zone can be addressed by a neighboring cell
- **Active mitigation may be employed as a last resort for particular susceptible victim receivers who are not isolated by their inherent geometry or passive mitigation techniques**
- **Backhaul Evolution @ 70 GHz**
  - Existing backhaul nodes will be protected in the current form having minimal interference
  - Future backhaul receivers should be 5G NR aware enabling efficient and effective coexistence
  - Recommend that interim backhaul deployments require contemporary wireless implementation with resilience to sparse impulsive interference.

Nokia respectfully requests that the 70/80 GHz Bands remain under consideration as a critical part of the 5G spectrum pipeline in the U.S. and globally.

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